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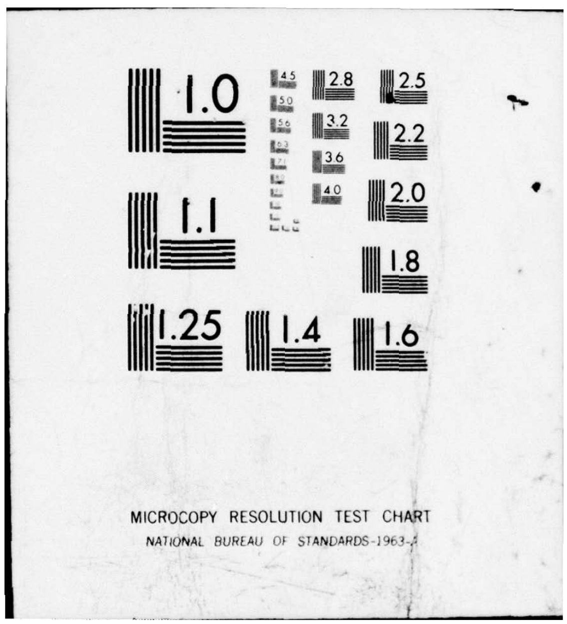
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W. W. Hansen Laboratories of Physics
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Stanford, California 94305

Free Electron Laser

FINAL REPORT

AIR FORCE CONTRACT: F49620-76-C-0018

For the Period:

15 July, 1976 - 8 October, 1976

CO-PRINCIPAL INVESTIGATORS:

J. M. J. Madey and H. A. Schwettman

December, 1976

In the period 15 July - 8 October, 1976, construction of the high current pulsed gun was completed and the system was used with the superconducting accelerator to generate a high current 24 MeV electron beam. Experiments were conducted with the free electron laser oscillator at 10 ~~μ~~ MICRONS.

The pulsed gun consists of the electron gun and the electronics to drive the gun. The electronics was designed to the gun at a rate corresponding to the round trip optical transit time for the FEL resonator (11.8 MHz) while maintaining the pulse length below 1.5 nsec. The previous work had established that an instantaneous peak electron current $\gtrsim$ 320 mA would be required for operation above threshold at 10.6 μ . The corresponding gun current would be 1/10 - 1/30 of this value due to the compression of the electron pulse from the gun in the buncher and capture section.[1] The gun would therefore be called on to emit a peak current of the order of 12 - 36 mA within the phase space defined by the acceptance of the injector.

The standard accelerator gun consists of spherical cathode, a cylindrical first anode enclosing the cathode and a second anode maintained at + 100 kV relative to the cathode. Cathode emission is controlled by varying the potential between the cathode and the first anode. The speed with which the emission can be switched with this arrangement is low due to the high interelectrode capacitance and lead inductance and the low perveance of the gun.

To increase the switching speed one of the standard guns was fitted with an Eimac planar gridded cathode. The cathode assembly was designed for fast pulse operation and a pulsed emission current in excess of 100 mA was obtained with a pulse width, of 2 nanoseconds. Unfortunately, only 0.15% of this current was emitted into the acceptance of the injector. Application of computer analysis indicated the problem lay in the contour of the new cathode and also that there was no simple means to improve the performance of the basic design.

It was therefore decided to construct a SLAC-type pulsed gun. The SLAC gun had been designed specifically for use with the Eimac gridded cathode (Fig. 1). The cathode and anode geometry for our gun was taken directly from the SLAC design. The envelope and mounting flange were modified for installation on the SCA injector and a bellows seal was added to permit adjustment of the cathode-anode spacing. Based on the calculated emittance[2] for this design it was anticipated that a peak current in excess of 100 mA into the acceptance of the injector would be available under pulsed conditions. The measured current was lower by an order of magnitude.

The performance of the gun was optimized by increasing the gap between the cathode and anode to twice the value indicated in the SLAC design. At a net gun current of 280 mA a peak current of 16 mA was emitted into the 0.57 π mc-cm acceptance of the injector. There is some evidence that the current into the injector was limited by space charge. While it was possible to obtain a larger net emission current from the gun, the additional emission did not increase the current to the injector. (Since the emittance of the accelerated 24 MeV beam in the accelerator's normal configuration is better than required for operation of the FEL, a measurement was also made with the injector modified to accept a beam with an emittance of 1.1 π mc-cm, twice the normal value. The gun delivered a peak current of 51 mA into this emittance.)

The performance of the SLAC gun indicates that the emittance is at least a factor of three worse than the calculated value. The SLAC operating data is not inconsistent with our observations--SLAC does not require a particularly high quality beam. We believe the discrepancy is traceable to the limitations of the computer code used to estimate the emittance. The code's ability to handle complex boundary conditions is limited. As a consequence the code can not follow the motion of the electron from the cathode through the grid but rather must replace the grid mesh by a constant potential "transparent" plane. The code neglects the spread in transverse momentum of the electrons introduced by the variations in potential around the real grid wires.

Comparison of the performance of the gun with the requirements of the FEL oscillator (page 2) indicates that the gun is conditionally adequate for operation above threshold. The observed peak current of 15 mA with the injector in its normal configuration would be adequate assuming the calculated value of 30 for the ratio of the instantaneous peak current in the accelerator to the peak gun current. The measurements indicate that the current can be raised by increasing the acceptance of the injector although it remains to confirm that this will not affect FEL operation.

Electronics: Approximately -20 volts was required to cut off cathode emission while +200 volts grid drive was sufficient to obtain the required emission current under short pulse conditions. As previously noted the grid drive had to be synchronized with the RF field accelerating the electron beam. The gun had to be pulsed once every 110 RF cycles and the objective was to generate an electron pulse less than 1.5 nsec in length timed to optimize the current into the accelerator.

Grid drive was generated using a step recovery diode (SRD) pulse generator driven by an 11.8 MHz phase locked crystal oscillator. The SRD pulse generator yielded 1.1 nsec fwhm pulses with an amplitude of 40 volts. A three stage vacuum tube power amplifier was used to raise the pulse amplitude to 300 volts. The pulses were generated at low potential and were coupled to the cathode at 100 kV through a high voltage coaxial isolation transformer. The timing of the drive pulses were set by adjusting the phase of the 1300 MHz reference signal to the VXO. A photo of the drive pulse at the output of the 100 kV isolation transformer is shown in Figure.2.

The Experiment: The width of energy spectrum of the high current pulsed beam when accelerated to 24 MeV with the injector acceptance set at 0.57π mc-cm was 0.05%. This was indistinguishable from the spectrum obtained with a cw beam. The mean energy of the pulsed beam was $\approx 0.2\%$ higher than the energy of a cw beam at constant accelerating field gradient, a phenomenon attributed to the finite response time of the accelerator's amplitude feedback control system. The spectrum obtained with the injector acceptance set to $1.1\ \pi$ mc-cm was noticeably broader but still better than 0.1% . These results were generally consistent with our expectations for the system.

Based on the successful test of the gun, a series of experiments were undertaken with the FEL oscillator. In our plans for the experiment we divided the effort into two phases. In the first phase, measurements of the single pass gain were to be made while varying the electron beam energy steering, radius and injector acceptance to determine the optimum operating conditions. In the second phase, the effort would be directed towards resonator alignment and the attainment of operation above threshold.

In the first phase as instantaneous peak gain of 22% per pass (Fig. 3) was observed with the injector acceptance set at the nominal valve. The peak electron current for this measurement is estimated at 480 mA. The 1/e half linewidth was 0.6% . The figures for the peak gain and current were calculated assuming the theoretical 2^{o} bunch length. A gain/pass of 48% would have been anticipated with the 0.4% 1/e half-linewidth observed in the previous single pass gain measurements.

An instability in the position of the electron beam interfered with the completion of both the first and the second phase of the program. The degradation in linewidth is symptomatic of the problem caused by the instability . The electron beam has to be maintained within a circle of the order of 1 mm in diameter at the 2.5 kgauss field used in the experiment. While no problems were experienced with beam stability in previous runs, in this run the beam began to drift slowly parallel to the optical axis early in the experiment. The amplitude and rate of drift increased as the run progressed. When at the end of the run the position of the beam could not be held steady for more than 5-10 minutes, an inadequate time to complete the normal tune up procedure.

Despite the instability an effort was made to measure the gain/pass with a 1.4 amp electron beam obtained by setting the injector acceptance mc-cm and also to search for evidence of laser action. The gain observed with the high current beam was approximately the same as that obtained at 480 mA. It is not known with certainty whether this result reflects the larger emittance of the high current beam or the difficulties of keeping the drifting beam in alignment.

A short series of measurements with the oscillator was undertaken early in the run with the low emittance beam. The spontaneous power emerging from one of the partially transmitting resonator mirrors was observed as the Q of the cavity was spoiled and also, as the orientation of the output mirror was scanned ± 0.5 milliradians in the x-y plane. The moveable 45° mirror used to reflect the radiation from the CO_2 TEA laser onto the optical axis within the cavity provided a convenient means to spoil the Q ; the power through the mirror fell by ~ 10% when the 45° mirror was run into the cavity. The resonator mirror scan had no observable effect on the power output.

Prior to the run, a substantial amount of work had been done to prepare and align the experimental optics. The endcaps of the helium dewar for the superconducting helical magnet were removed and the magnet bore was polished, cleaned and realigned. The extreme ends of the tube lining the magnet bore were bent back onto the optical axis in an effort to correct the curvature of the tube. This operation had no measureable effect on the attenuation. Some research was also conducted into the possibility that the bore of the tube could be gold plated. This effort proved impractical due to the difficulty in securing a uniform bright deposit over the 20' length of the magnet.

A substantial effort was also mounted to modify the resonator for operation at 3.39 μ. At this wavelength it is possible to design a resonator in which the lowest order radial mode is decoupled from the magnet bore. With such a resonator the losses would be reduced to the order of the diffraction losses and the mirror transmission with a concomitant reduction in the electron current required for operation above threshold. A pair of resonator mirrors were acquired for this purpose and an effort was made to develop a HeNe plasma tube for inclusion within the resonator to check the mirror alignment. The scheme has temporarily been frustrated by the complications encountered in operating a plasma tube with an aperture sufficient to accomodate the diameter of the fundamental mode for the 12 meter resonator.

Work has also continued in the experimental optics. During the course of the experiment it is necessary to observe (1) the total spontaneous power emitted by the electron beam, (2) the spectrum of the radiation, (3) the modulation imposed on the radiation from the TEA laser by the electron beam, and, (4) the signal emerging from the output window of the FEL oscillator. Each of these observations requires a different optical set up. Remotely activated moveable mirrors were installed for the most recent experiments to permit reconfiguration of the set-up from the control room.

FOOTNOTES:

1. The calculated bunch length at 24 MeV is 2° yielding a charge density in the bunch 30 times the charge density in the 100 kV beam from the gun. The experimental upper limit to the bunch length is 6° corresponding to a factor of 10 enhancement in the charge density.

2. The electron trajectories were calculated using the code developed by Bill Hermansfeldt at SLAC.

Figure Captions:

Figure 1: Cathode and Anode Geometry in the SLAC gun.

Figure 2: Gun drive pulse at the output of the 100 kV isolation transformer (2 nsec/div, 50 v/dV). The incident pulse is negative. The positive pulse which follows is reflected from the cathode.

Figure 3: Gain/pass vs. electron energy with the high current pulsed gun. The instantaneous peak gain reached 22%/pass at an instantaneous peak current of 480 mA.

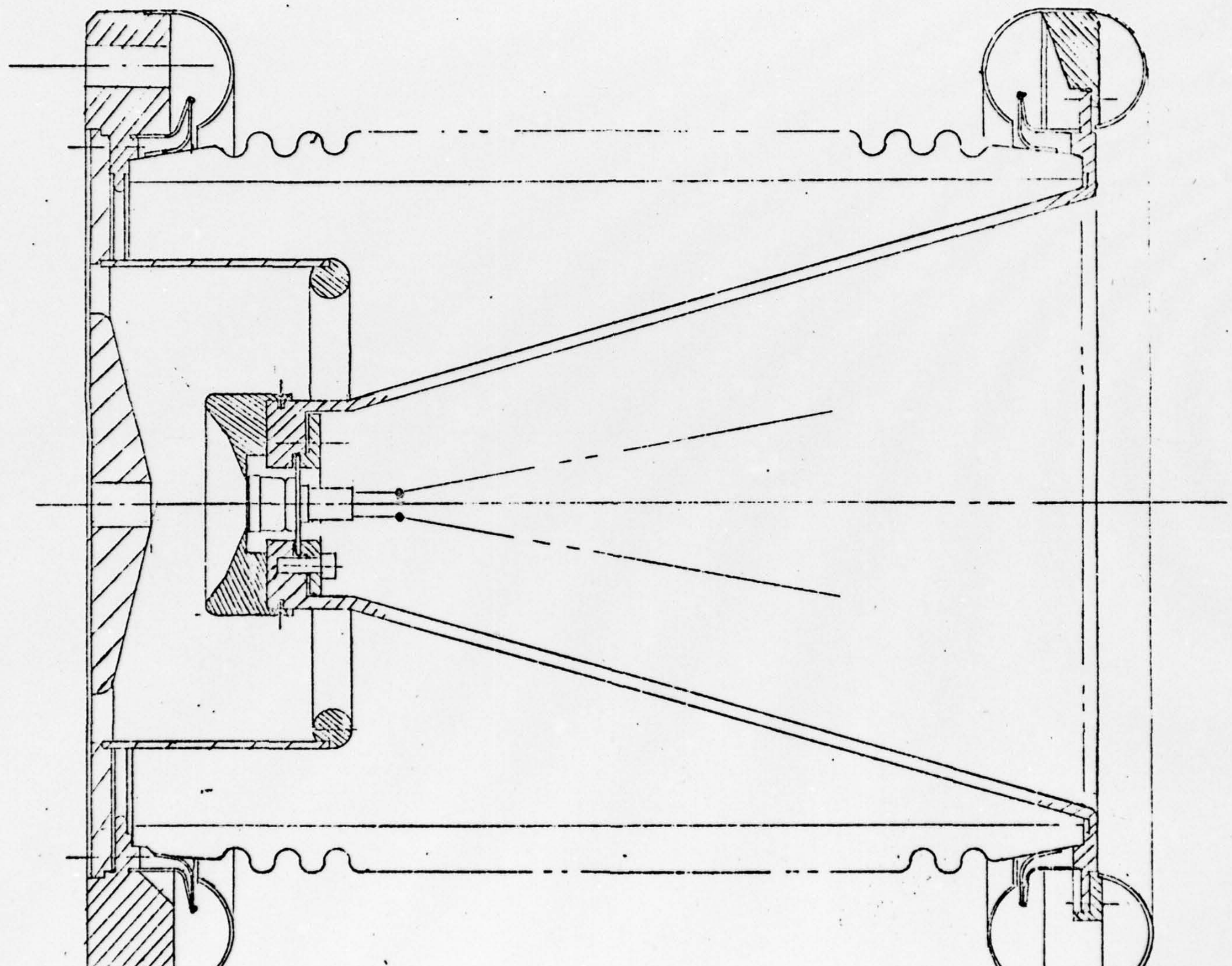

Figure 1

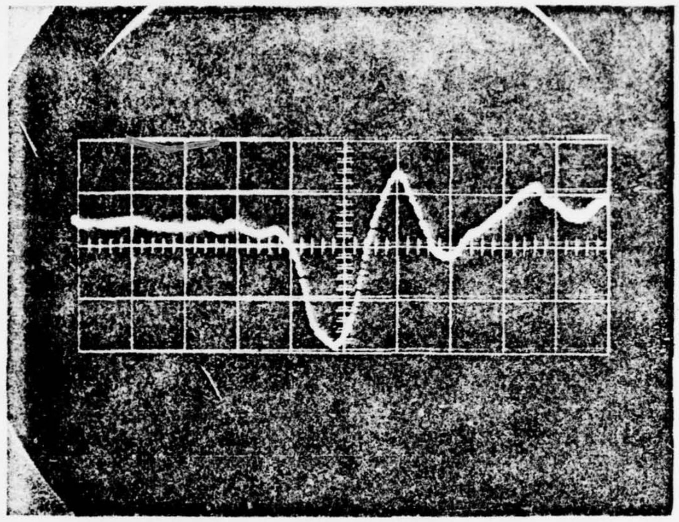

Figure 2

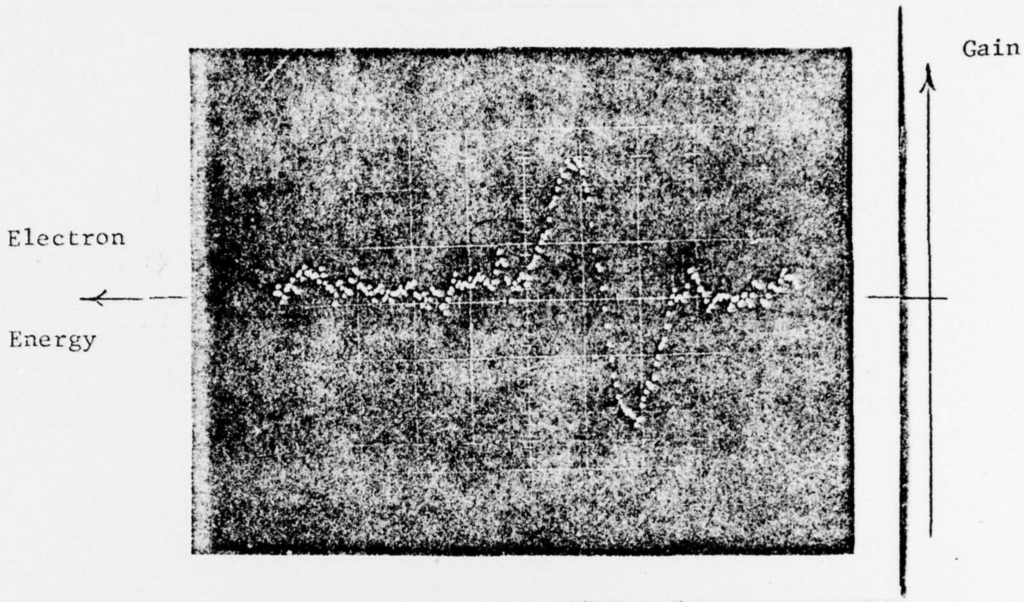

Figure 3

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The response of bimetallic junctions to shock loading was investigated using a new simplified geometry in which the circuit of interest is completed by the impact. Techniques for measuring the 1 millivolt level signals were developed within this geometry with the extensive use of null experiments in which both parts of the junction were of the same material. It was shown that the use of a ferromagnetic material introduces a demagnetization signal that is not well characterized, which puts measurements of termal E.M.F.s

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BLOCK 20 ABSTRACT (Continued)

measured in nickel under shock loading conditions in some doubt. Results of experiments involving a nickel 80% chromium 20% alloy indicate that the E. M. F. s involved are anomalously high, in agreement with previous work done elsewhere. The dependence of one-deminsional conditions has not been comple tely characterized but the indication is that there is indeed some dependence.